Update on couplers for SC resonators

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PIP-II meeting

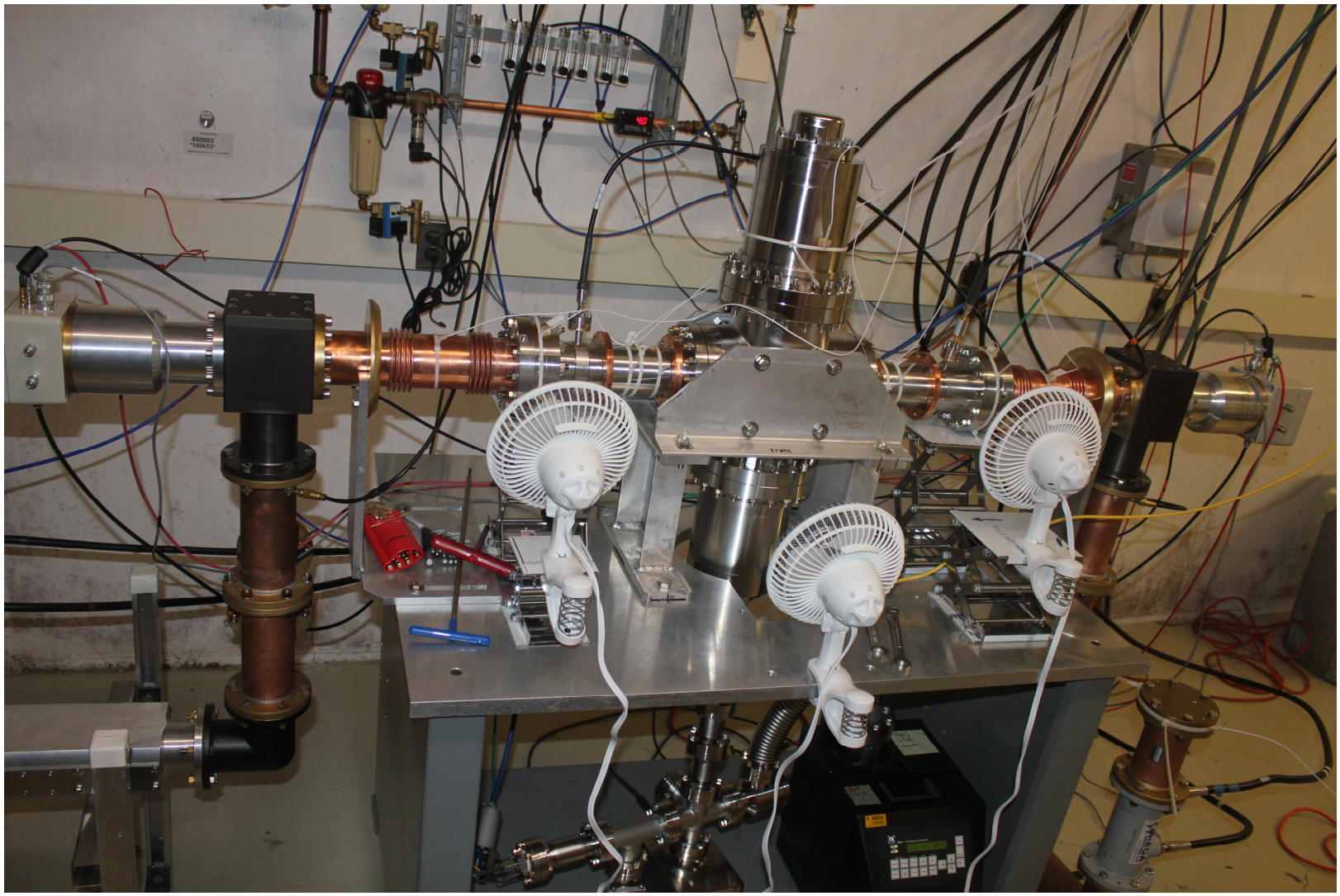
19 July 2016

Good news:

We successfully completed the High power test of first two serial 325 MHz couplers made by Mega Industries.

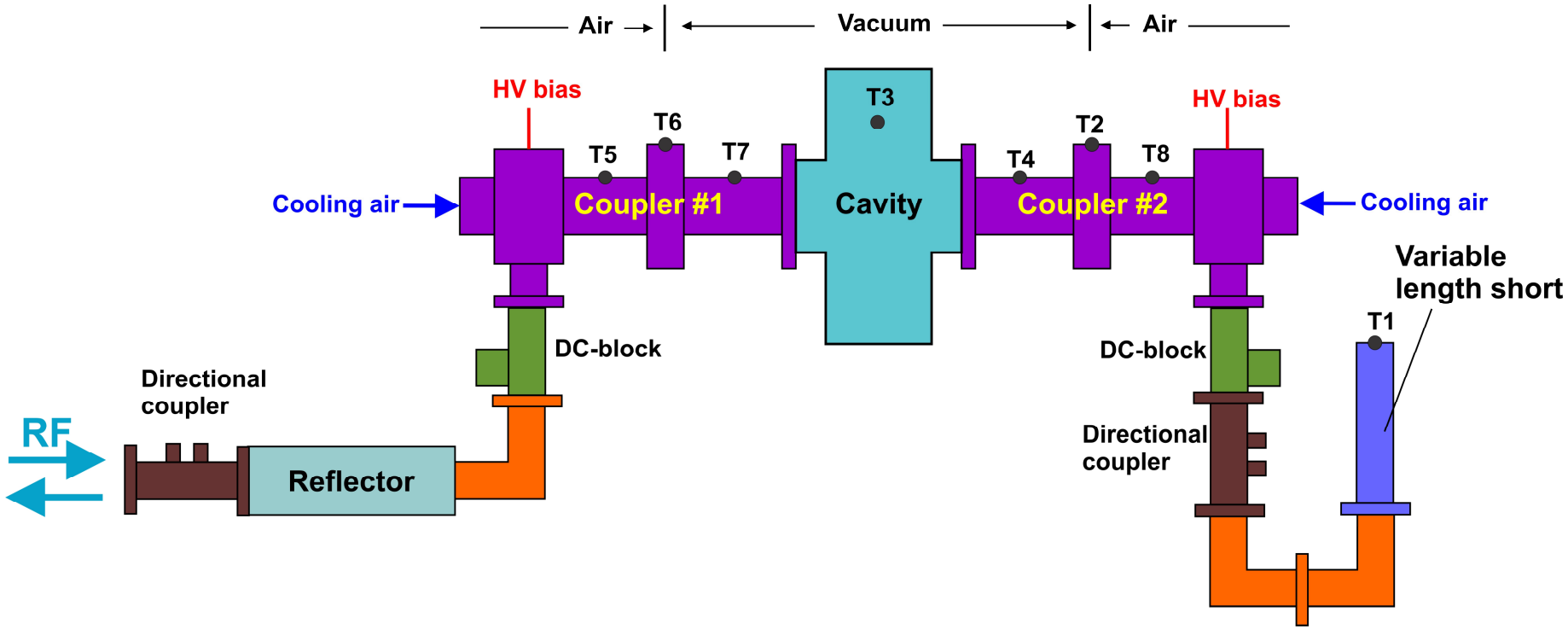
- Couplers were tested in coupler test stand at room temperature.
- Power level was 20 kW, CW, full reflection.
- Couplers were tested at four configurations with different reflected phase. Phase step - 90^{o}.
- Couplers were kept for 1.5 hour at each configuration.
- No evidences of high power in “air” sides of couplers (“vacuum” parts are not disassembled yet).

Details of the test:

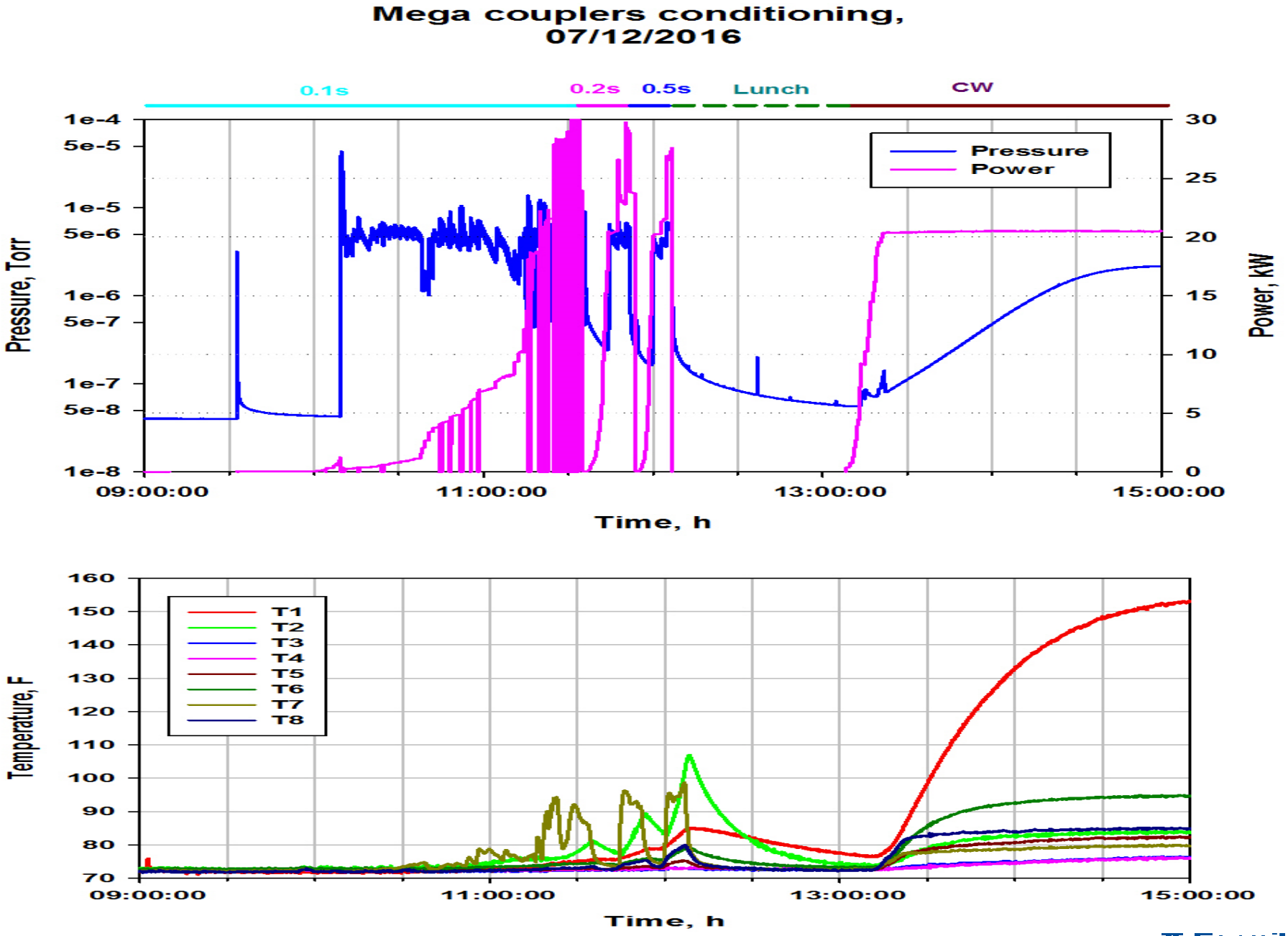


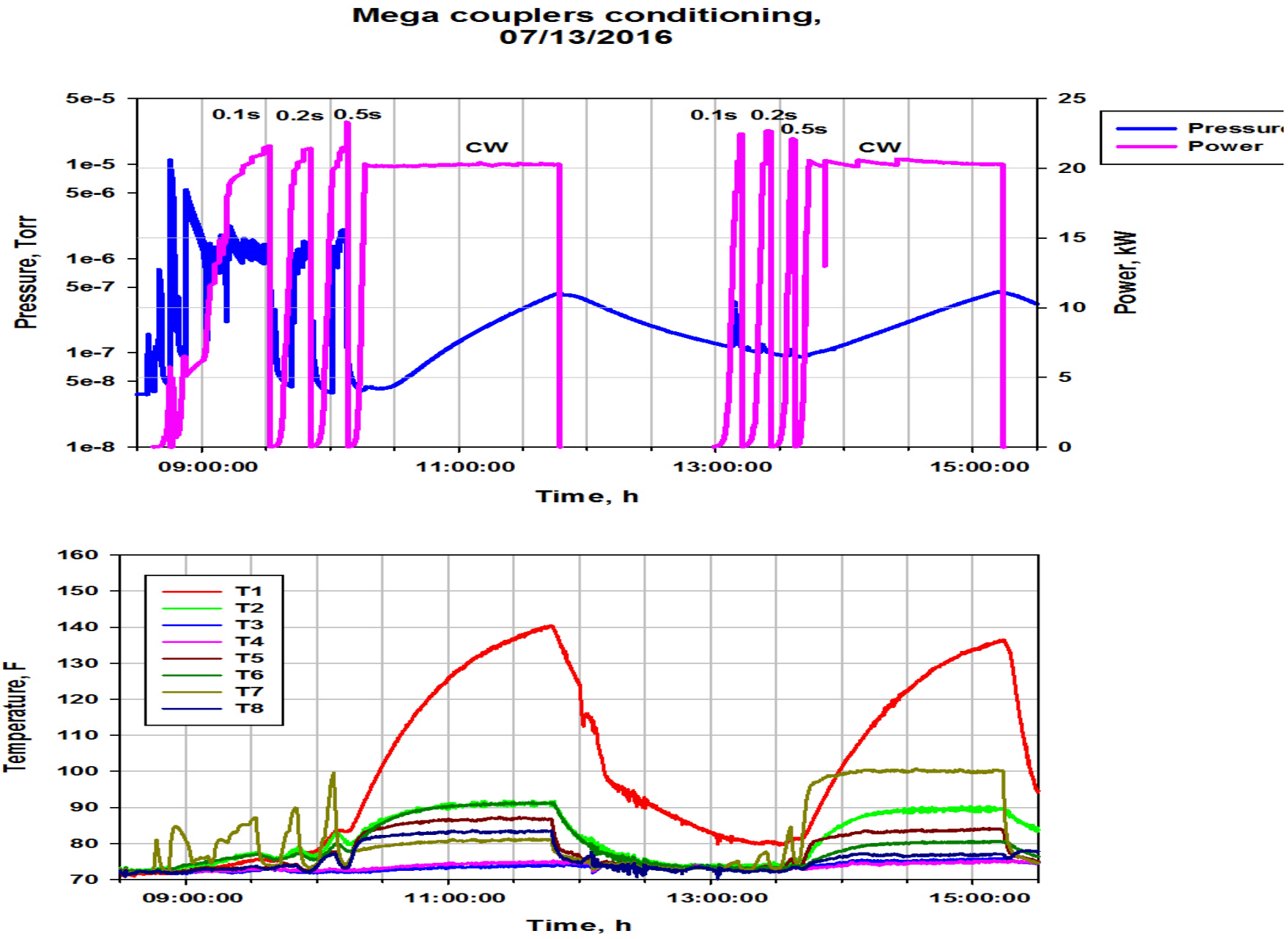
Coupler test stand in MDB

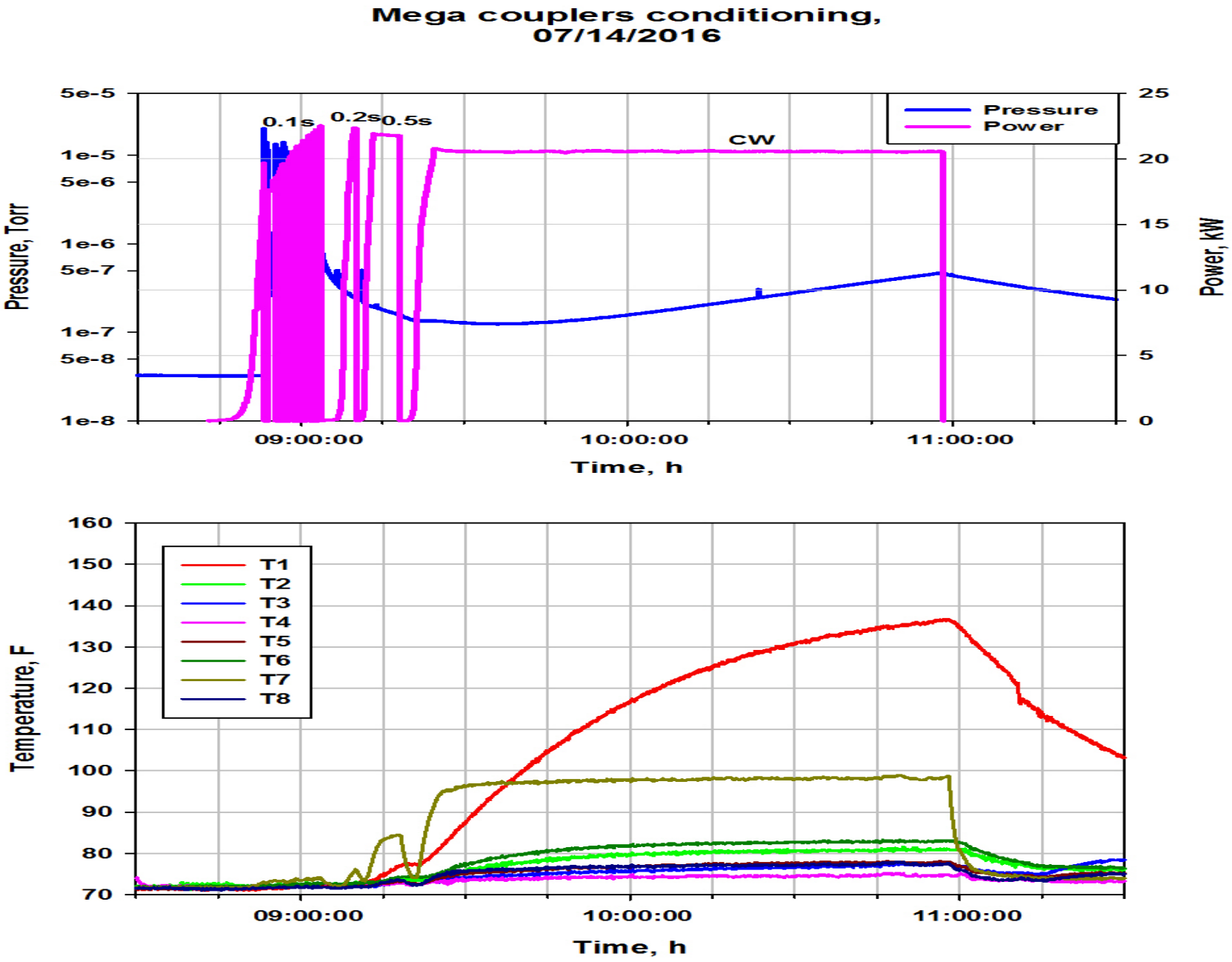
Configuration of coupler test stand:



Power amplification ~ 5


Mega couplers conditioning,
07/12/2016
0.1s
0.2s
0.5s
Lunch
CW
Pressure
Power
Pressure, Torr
Power, kW
1e-4
5e-5
1e-5
5e-6
1e-6
5e-7
1e-7
5e-8
1e-8
30
25
20
15
10
5
0
09:00:00
11:00:00
13:00:00
15:00:00
Time, h
T1
T2
T3
T4
T5
T6
T7
T8
Temperature, F
160
150
140
130
120
110
100
90
80
70
09:00:00
11:00:00
13:00:00
15:00:00
Time, h


Mega couplers conditioning,
07/13/2016
0.1s
0.2s
0.5s
CW
0.1s
0.2s
0.5s
CW
Pressure, Torr
Power, kW
Time, h
09:00:00
11:00:00
13:00:00
15:00:00
Pressure
Power
T1
T2
T3
T4
T5
T6
T7
T8
Temperature, F


Mega couplers conditioning,
07/14/2016
Pressure, Torr
Power, kW
Time, h
0.1s
0.2s
0.5s
CW
Pressure
Power
5e-5
1e-5
5e-6
1e-6
5e-7
1e-7
5e-8
1e-8
25
20
15
10
5
0
09:00:00
10:00:00
11:00:00
Temperature, F
T1
T2
T3
T4
T5
T6
T7
T8
160
150
140
130
120
110
100
90
80
70

Next step with Mega 325 MHz couplers:

- Couplers will be disassembled and visually investigated.
- Antennas will be electro-polished (to reduce the thermal radiation).
- Couplers will be tested with SSR-I cavities at CTC for checking performance and coupling.
- The rest 8 couplers will be tested at coupler test stand when they are delivered.

What happened before and some lessons:

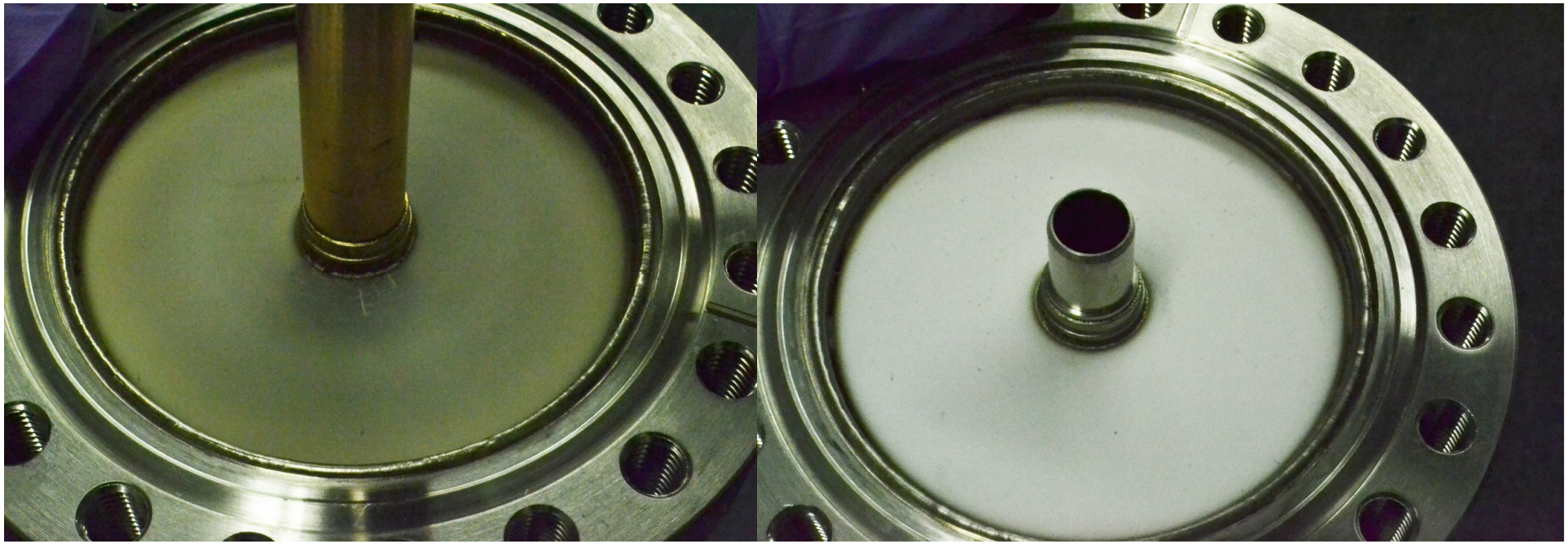
- Three prototype couplers were fabricated.
- Two couplers were tested at the coupler test stand.
  - Two couplers were successfully tested up to 30 kW, CW, full reflection.
  - Couplers were tested to failure. One coupler was destroyed at power level ~ 47 kW, CW, full reflection.
- Third coupler is used in STC with SSR-I cavity at power level ~ 10 kW, CW, full reflection. Coupler was installed without preliminary RF condition at test stand. Cavity reached the required accelerating gradient.
- Temperature measurements showed that thermal coupler properties are close to expected.

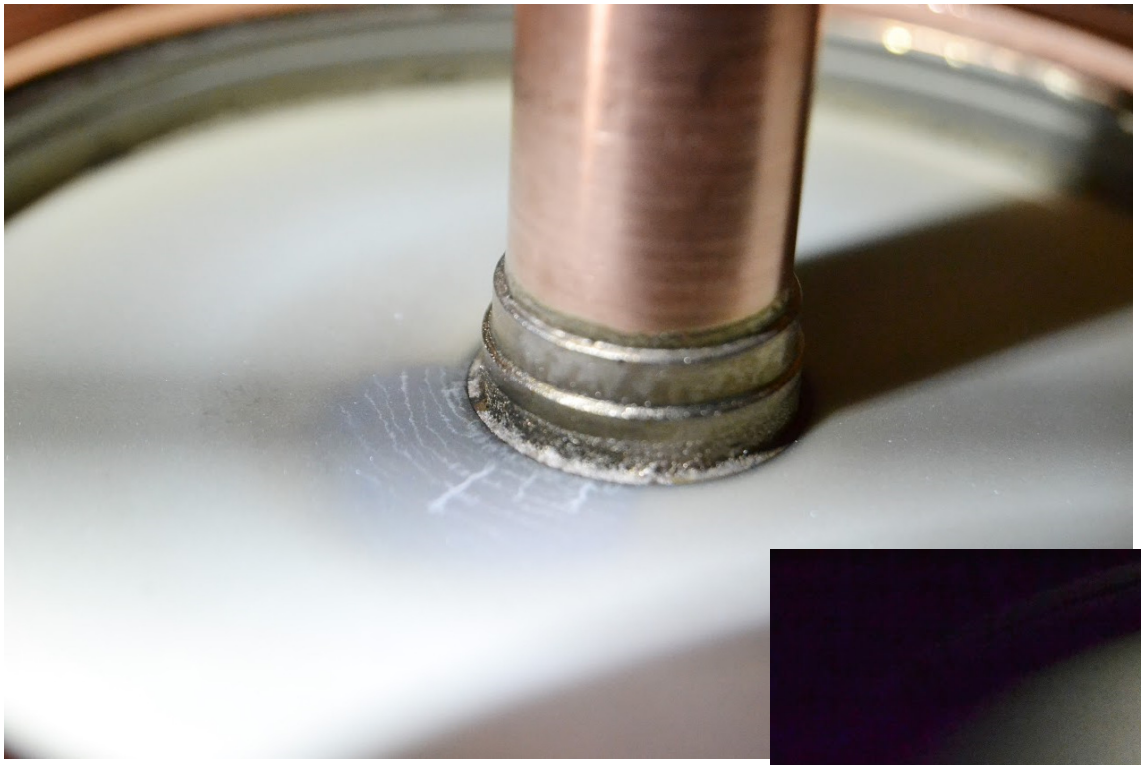
Conclusion:

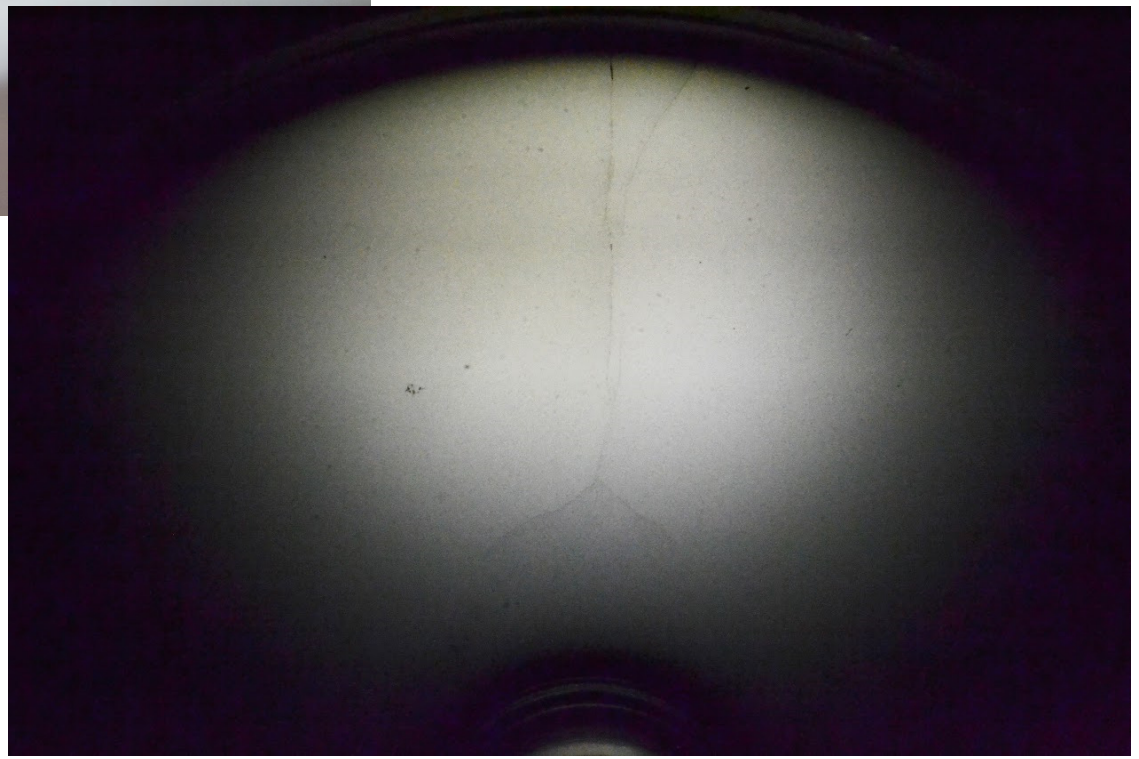
- Power limit of prototypes is 30 kW, < P_limit < 47 kW (CW, full reflection). But there is no statistic.
- Multipactor is not essential. Probably, coupler does not require a preliminary conditioning at test stand and can be conditioned with cavity. Experiments with next SSR-I cavities will give us final answer.
- Nevertheless, HV bias is useful to suppress multipactor completely. (Multipactor signs were observed at ~ 10 kW power in cavity-coupler assembly).
- HV bias is very effective for work with couplers at test stand at high power level (>10 kW).

Couplers failures

One coupler was destroyed at power level ~ 47 kW, CW, full reflection. It is big margin for SSR-I but not so big for SSR-II and not enough 650 MHz cavities (5 mA).

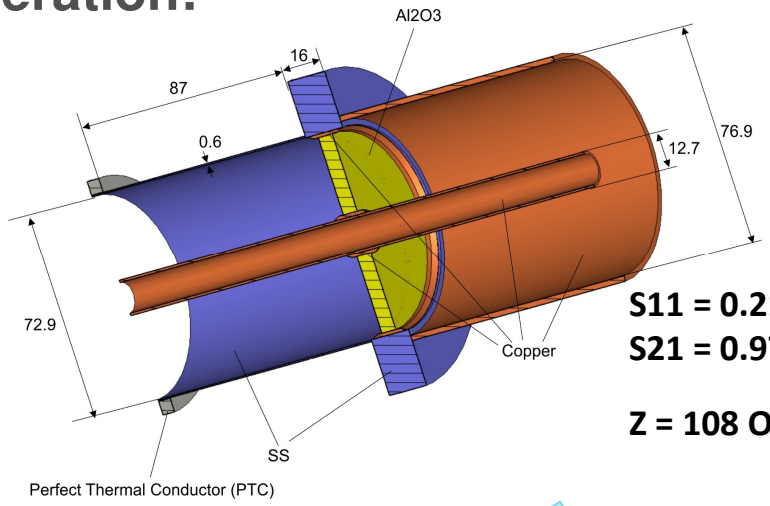






- Quality of brazing was not good (rather bad) from the beginning.
- The weakest point if window (I think) is the brazing inner conductor to the ceramics. The current density at inner conductor surface is Rout/Rin higher then at outer conductor. In our case Rout/Rin ~ 5.8. Heat density ~ 34 higher.
- The reasons why we use relative small Rin are:
  - To shift multipactor thresholder to higher power
  - To reduce cryo-loads to 2, 5, 80K (to reduce RF current)

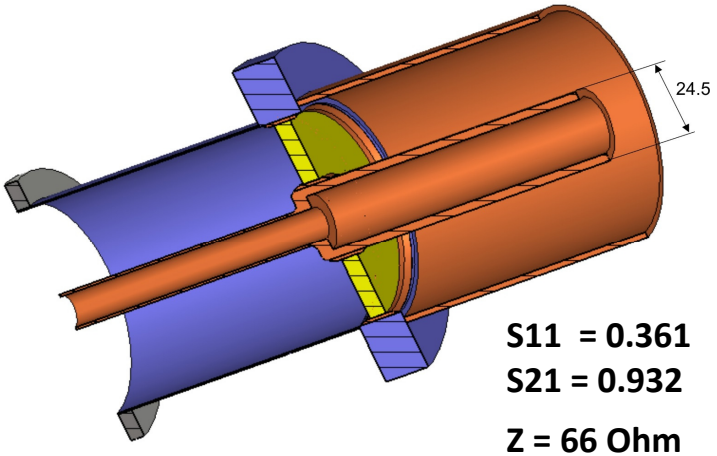
We are suggesting to increase inner conductor in brazing place in next coupler generation:



S11 = 0.212
S21 = 0.977

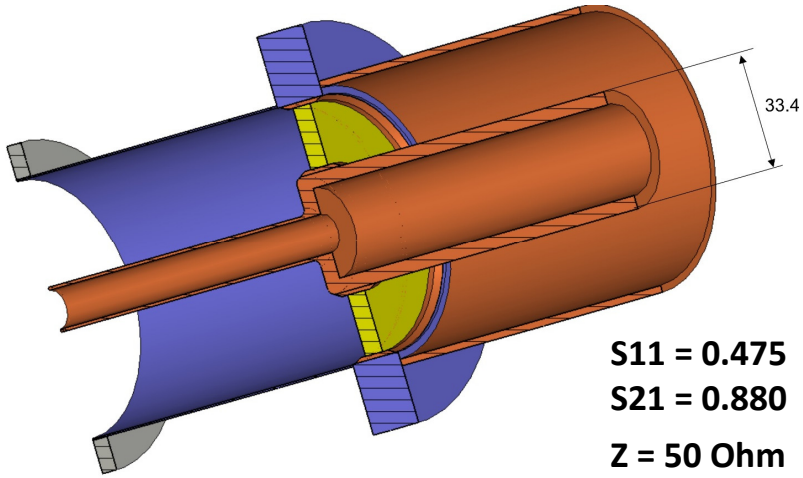
Z = 108 Ohm

OR



S11 = 0.361
S21 = 0.932

Z = 66 Ohm

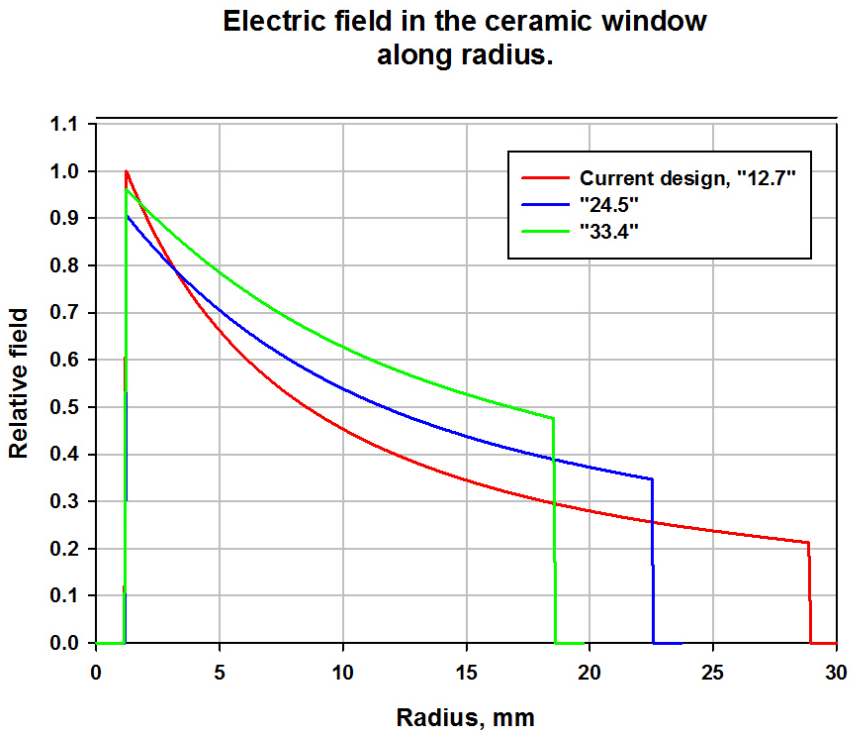


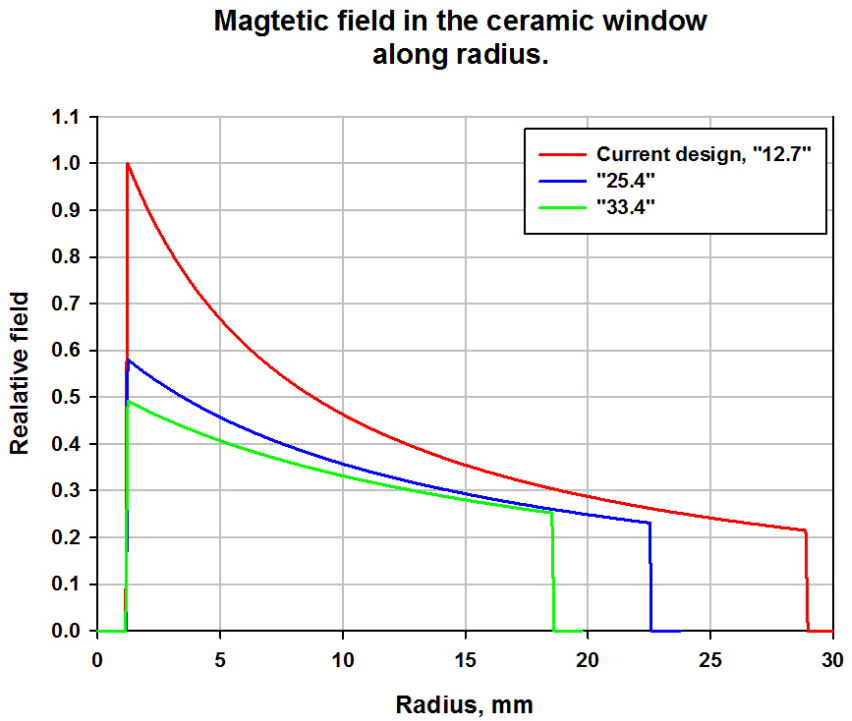
S11 = 0.475
S21 = 0.880

Z = 50 Ohm

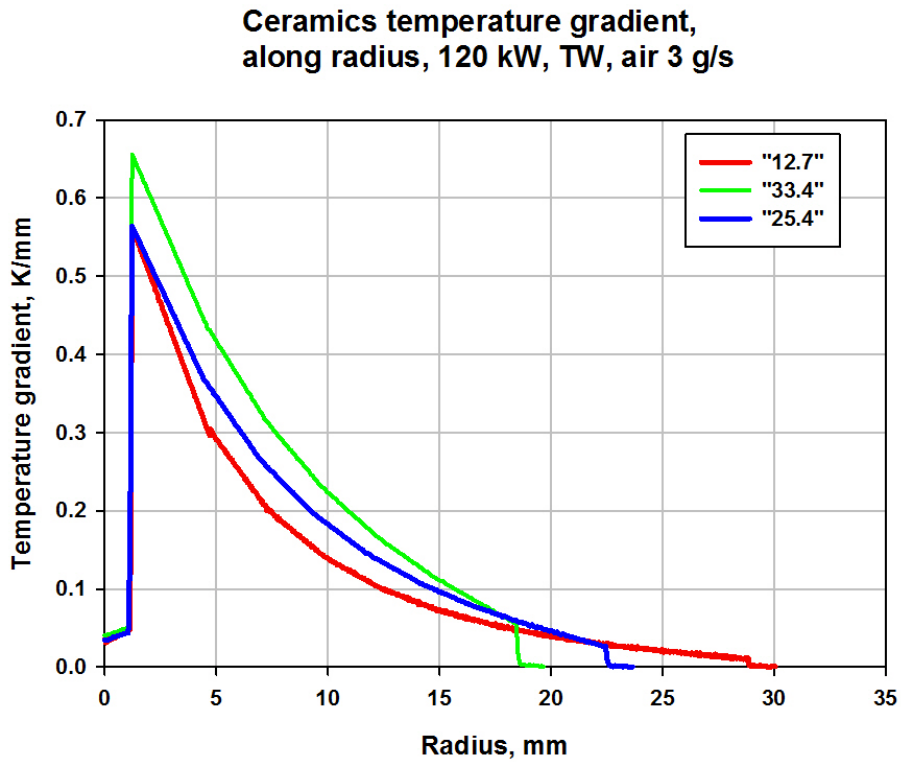
Fermilab

Relative electric and magnetic fields in the ceramic window (same transmitted power).





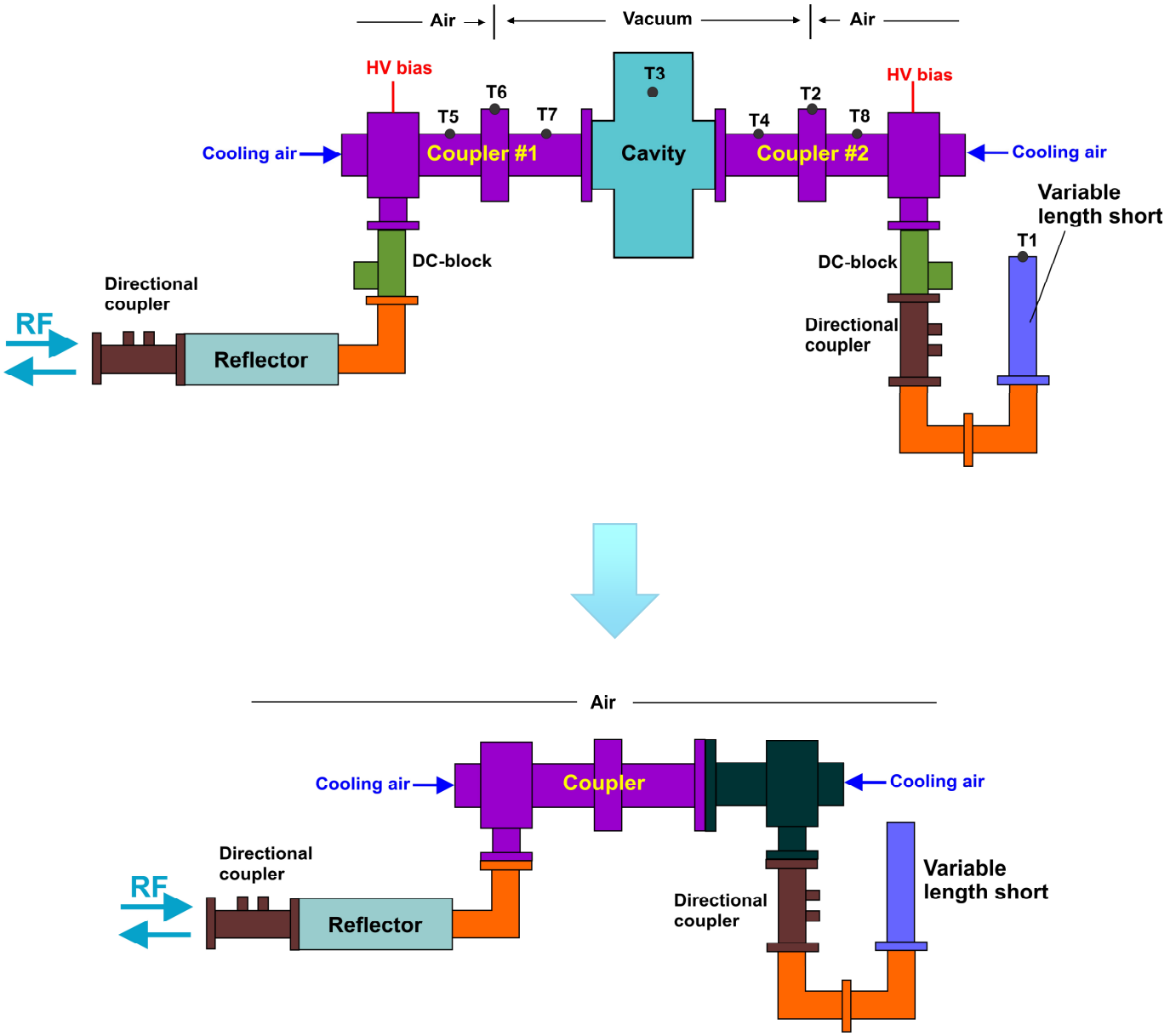
Bigger diameters do not decrease practically the maximum of electrical field but significantly decrease the maximum of magnetic field (density of current).



Simulations show that radial thermal gradient does not depend much on diameter of inner conductor. But probably tangential gradient responsible for crack of ceramic. Tangential gradient can be caused by defect/nonuniformity of brazing. In this case window with lower current/heat density has an advantage.

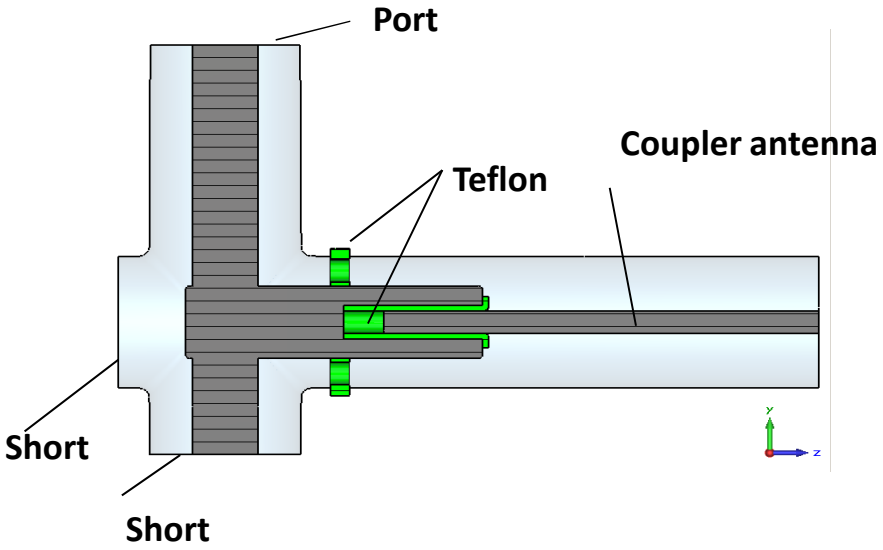
Not successful test of single coupler in air.

- To make coupler test simpler, faster and less expensive we decided to try to test a single coupler in air without cavity and second coupler.
- Logic:
  - Multipctor is not an issue and coupler does not require a preliminary conditioning (in vacuum).
  - We need only to check a power ability of ceremic window to avoid rough defects.
  - Window is symmetrical. One side works in air all time. Another side has to be able to stand the same power in air.

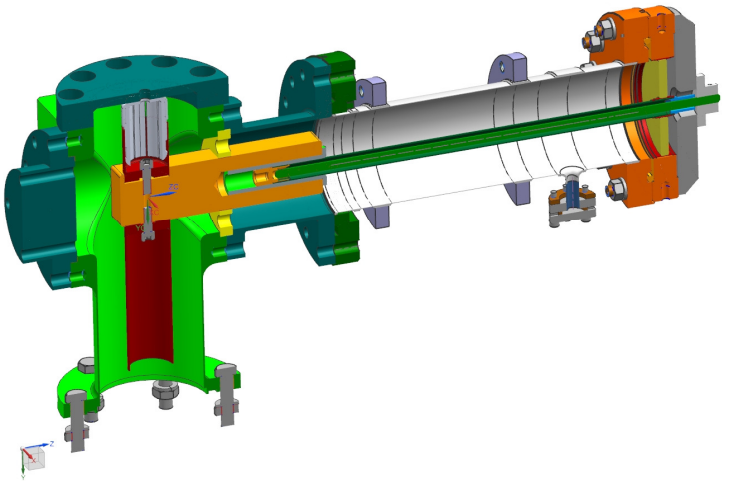

Air
Vacuum
Air
HV bias
T3
T6
T2
HV bias
T5
T7
T4
T8
Cooling air
Coupler #1
Cavity
Coupler #2
Cooling air
Variable
length short
T1
DC-block
DC-block
Directional
coupler
RF
Reflector
Directional
coupler
Air
Cooling air
Coupler
Cooling air
Directional
coupler
RF
Reflector
Directional
coupler
Variable
length short

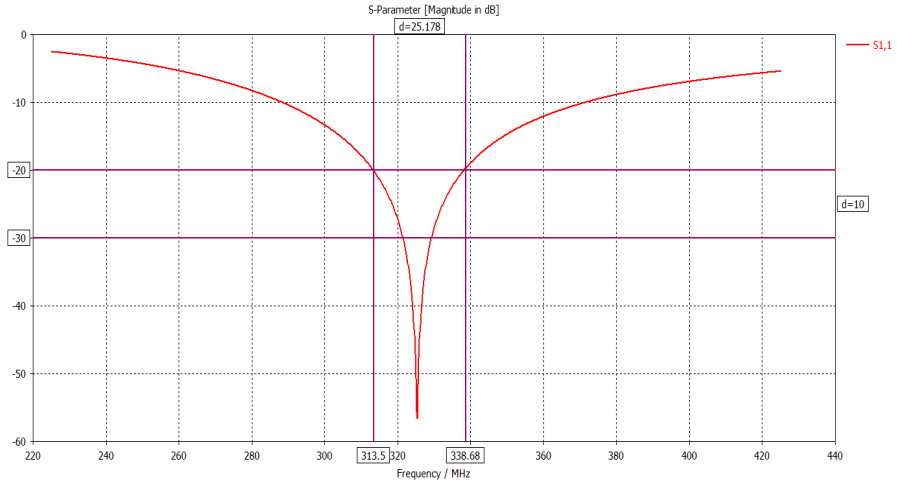
Fermilab

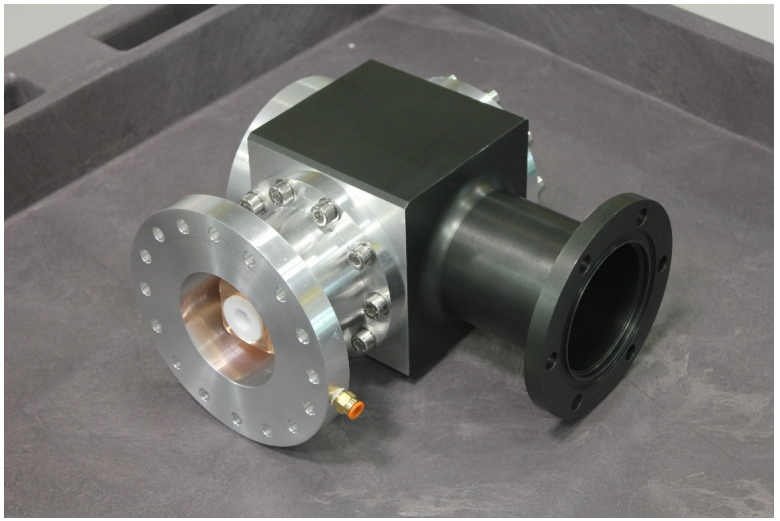
Electrical configuration



Mechanical configuration

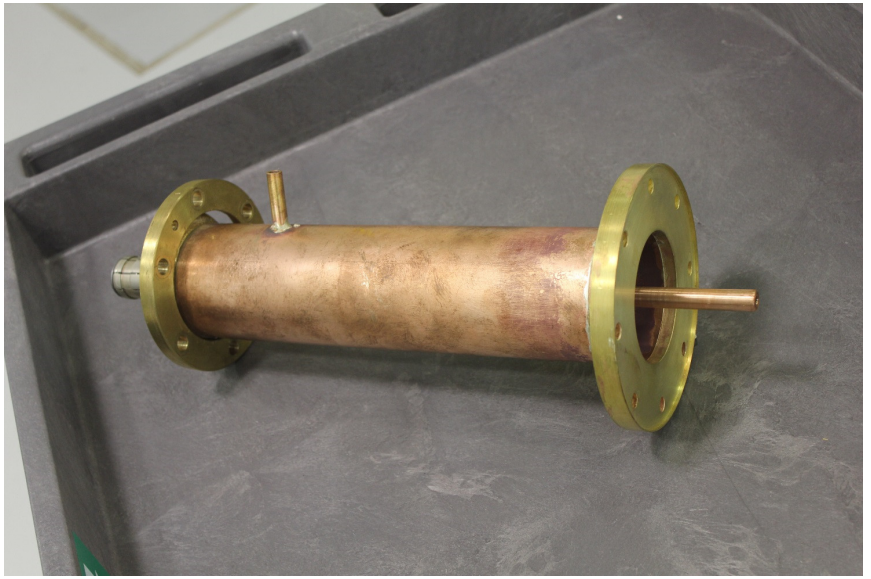




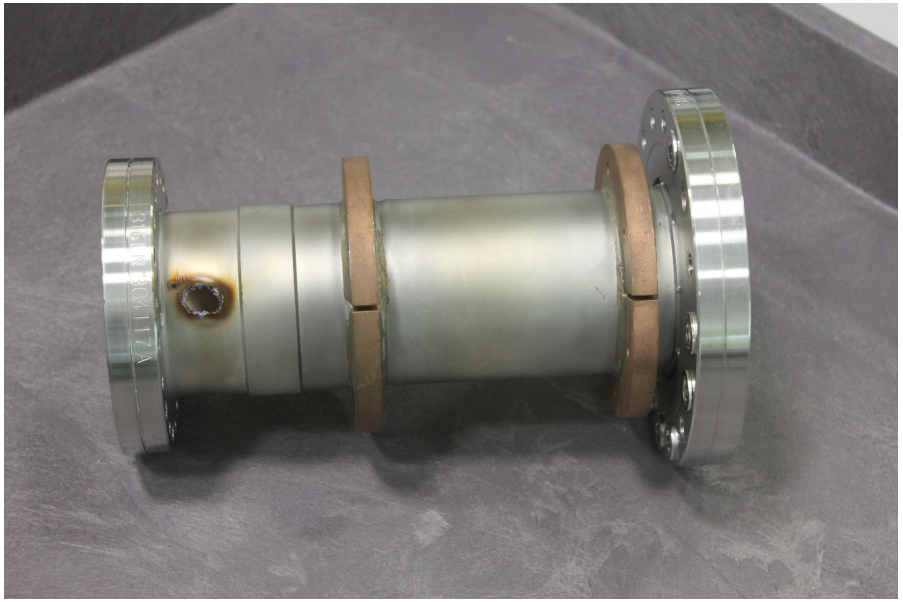


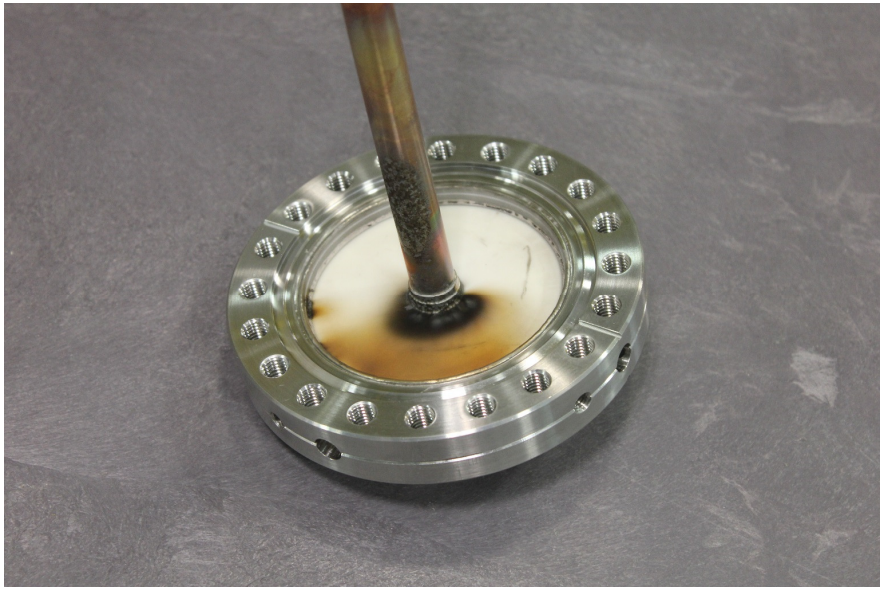
Ideal breakdown limit ~ 340kW, TW or 85 kW, full reflection.
30 kW, full reflection is operable limit, probably.

Tests with dummy coupler

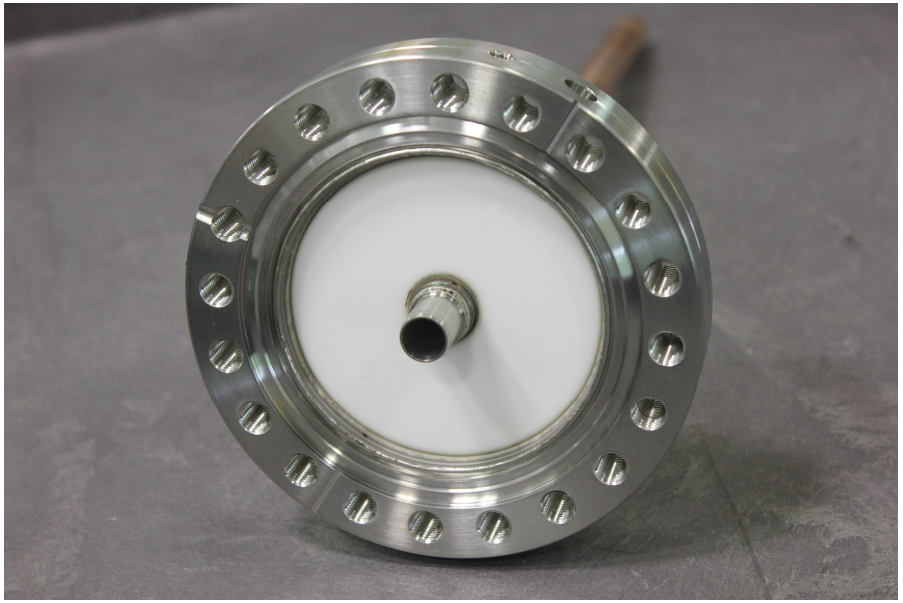


- First test was done without reflector at level 6-8 kW, full reflection (power depends on reflection phase). Was tested 4 reflection phase with 90 dgr step.
- Second test was done with reflector a power level 22 kW, full reflection, 4 step, 90 dgr, ~ 1 hour at each step.
- Both test were performed successfully. There no evidence of breakdowns, any damage or discoloration.
- We were quite sure in success of real coupler testing.
- But result with coupler prototype was astonishing, see next slides.

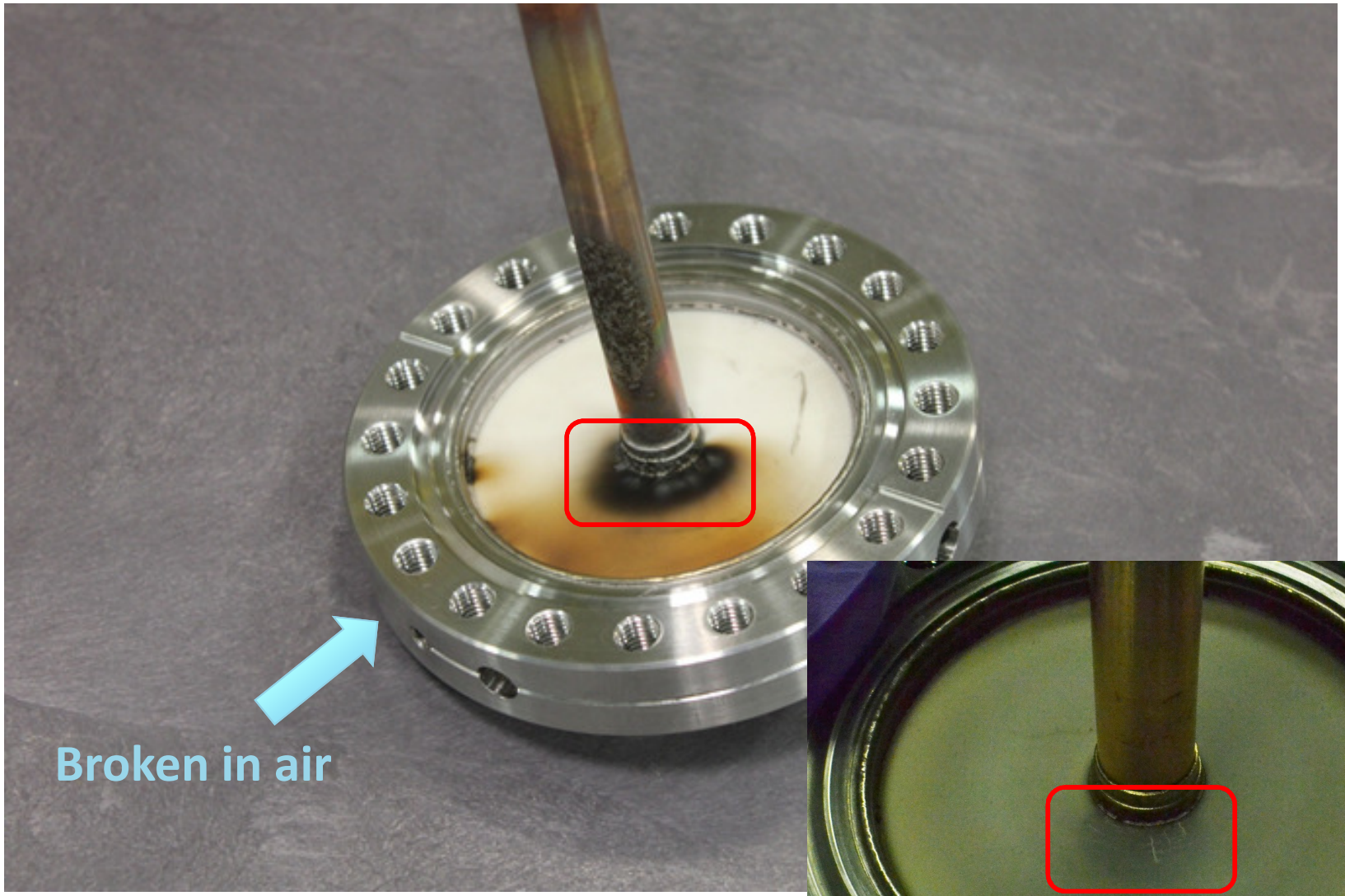


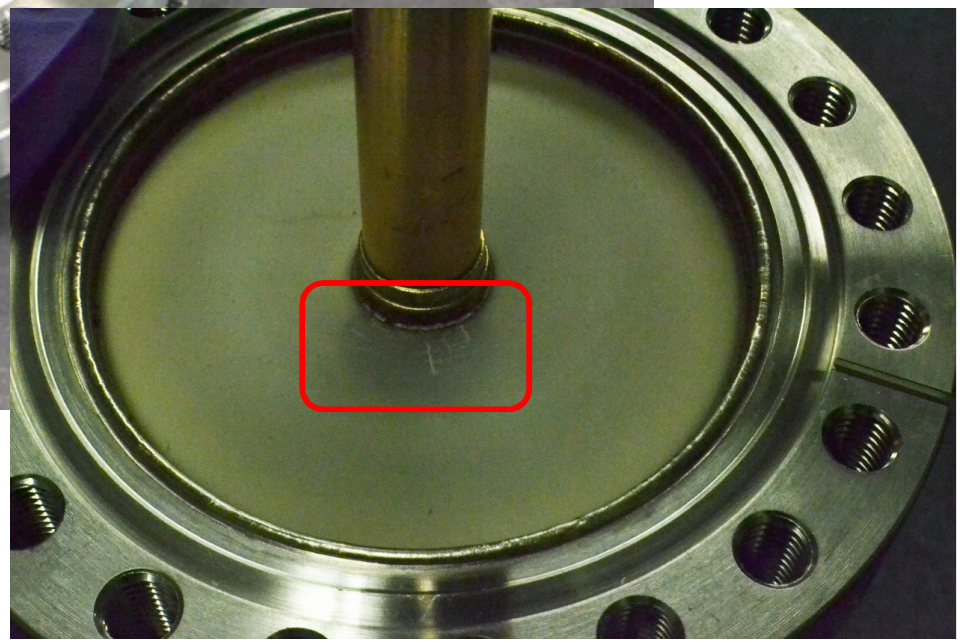


“Vacuum” side



“Air” side is clean,
no sign of breakdowns





Broken in vacuum

Fermilab

Possible explanation of air test results:

- Quality brazing of vacuum sides of windows were worse then air sides. It was clear from visual inspection.
- Air test reveals weak brazing point more clear then vacuum test. Good window has to sustain air test.
- Breakdown started at brazing point of inner conductor and initiated breakdown between inner conductor and outer conductor. Outer conductor is thing SS, 0.4mm and it was burned easily.

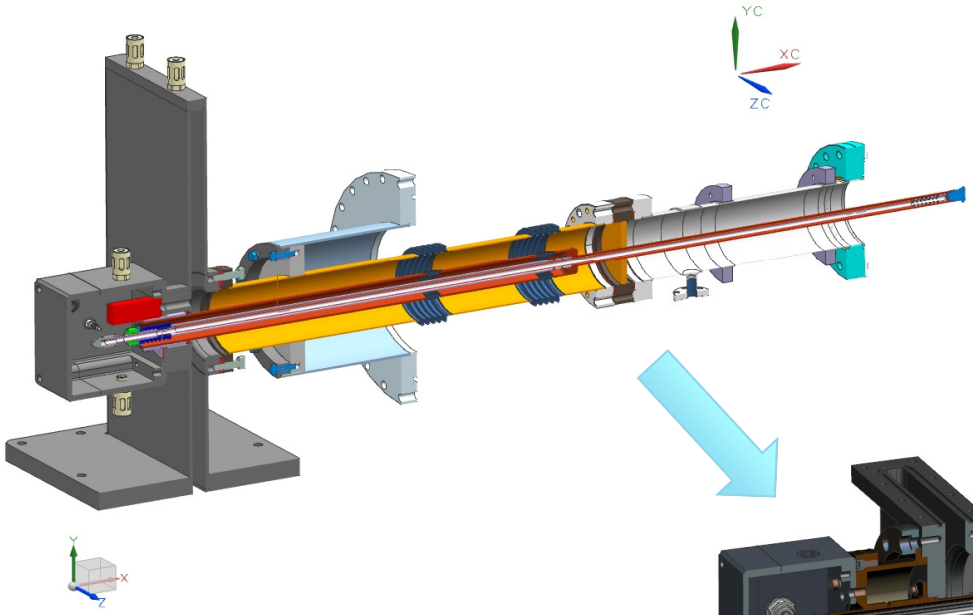
We suppose to clean the ceramic window and repeat the test.

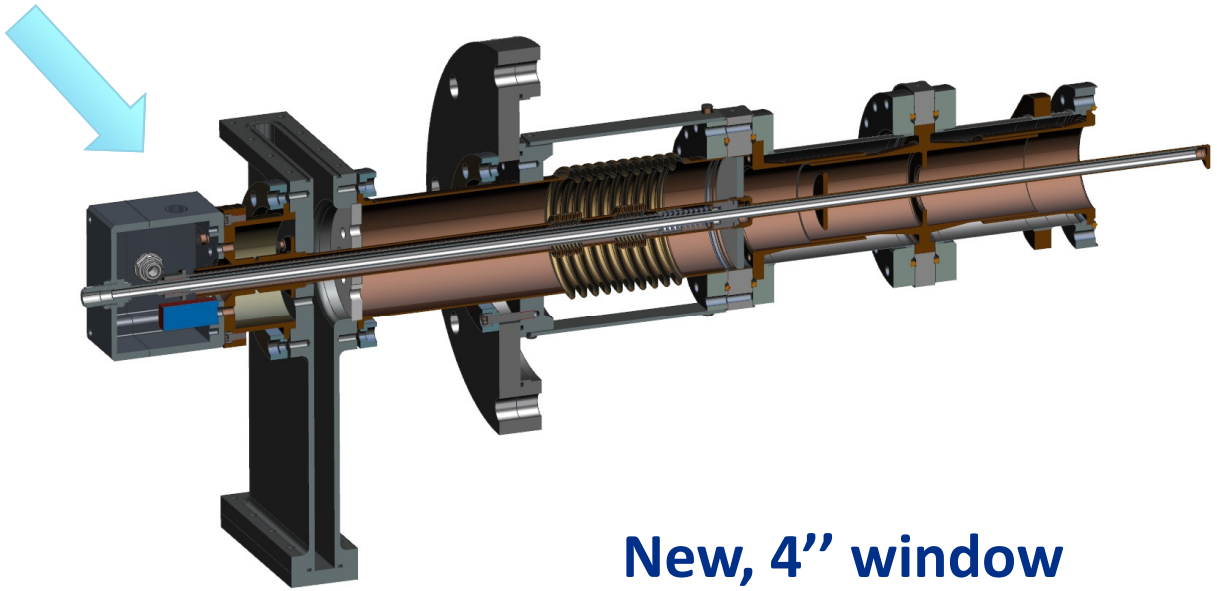
650 MHz coupler

- Based on tests results of 325 MHz couplers and on new ideas, the design of 650 MHz coupler will be modernized:
  - Diameter of ceramic window will be increased from 3” to 4” (to increase power limit).
  - Diameter of inner conductor of ceramic window will be increased from 0.5” to 1”. It will decrease a current density at brazing place and makes window less sensitive to brazing defects (more reliable).
  - Matching element will be placed to antenna. It will serve as shield of ceramic against charged particles.
  - Two versions of coupler are under design:
    - One uses EM shields instead of copper coating.
    - Other one utilize a traditional copper coating.

650 MHz couple, old and new designs

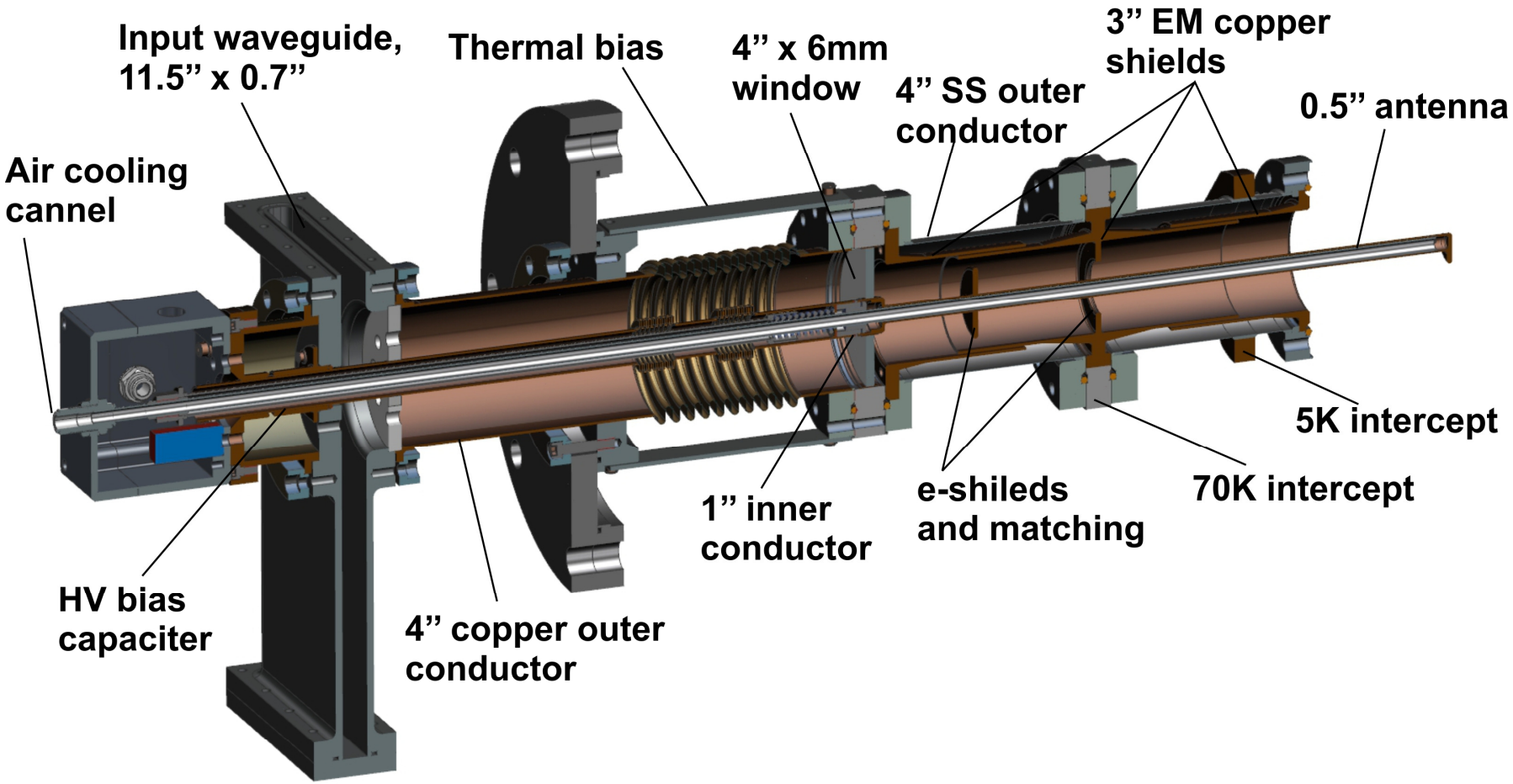
Old, 3’’ window



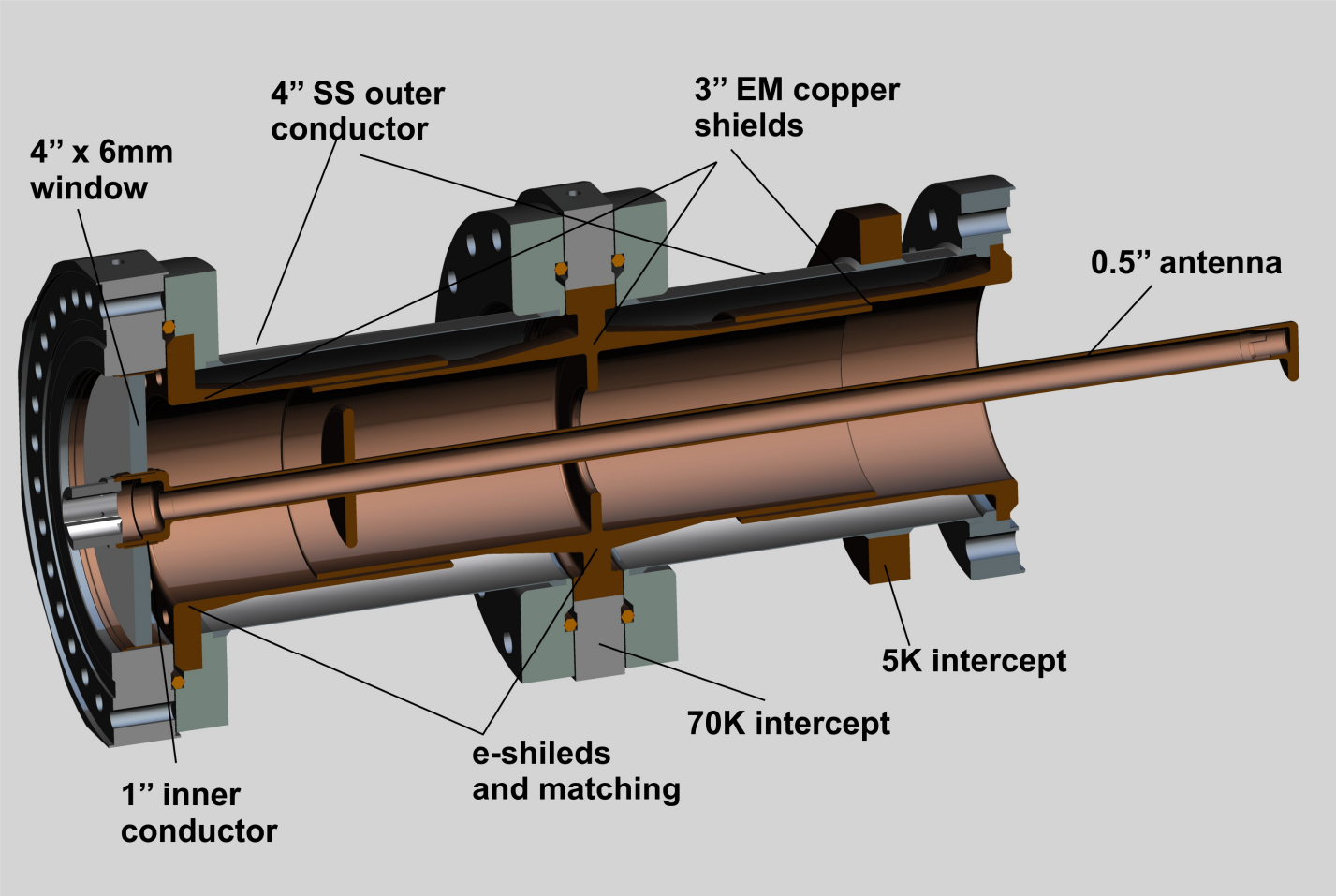


New, 4’’ window

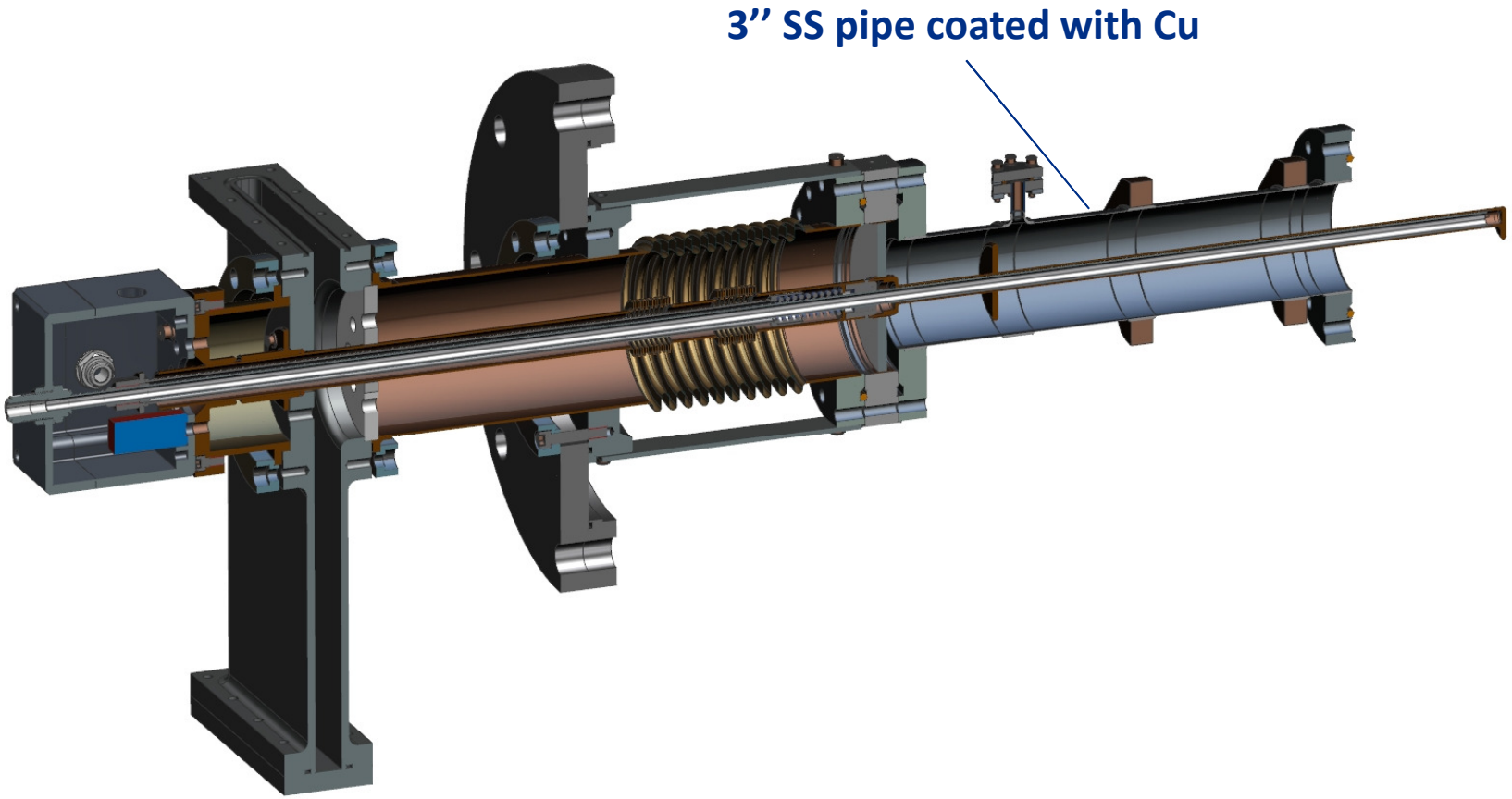
650 MHz coupler, structure, new design



650 MHz coupler, vacuum part.



650 MHz coupler, version 2



Cryo-loads of 650 MHz couplers

Static loads

Type	2K load, W	5K load, W	70K load, W
New	0.002	0.60	3.3
Conv. , 15 um	0.027	1.46	3.0

Total loads, 300 kW, TW, CW

Type	2K load, W	5K load, W	70K load, W	293K load, W
New	0.58	1.63	11.7	52.4
Conv., 10 um	0.96	8.8	26.6	48.1
Conv., 15 um	0.81	9.4	27.1	49.6
Conv., 20 um	0.86	9.8	27.5	50.3

New = 0.58*960 + 1.63*220 + 11.7*20 = 1149.4
Conv = 0.81*960 + 9.40*220 + 27.1*20 = 3387.6

New design requires ~ 3 times less power of cryo-plant.

We will to have a design review for 650 MHz coupler soon.
Main technical properties will be presented there in details.

Thank you.